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Tehnologija izdelave in karakterizacija gradientnega ulitka

Manufacturing Technology and Characterization of Gradient Casting

Izvleček

Ta prispevek obravnava izdelavo sestavljenih ulitkov za valje, ki se imenujejo tudi gradientni ulitki. Izdelavna tehnologija je kombinacija vodoravnega centrifugalnega litja legirane bele litine (dve fazi) in težnostnega litja jeder v tretji fazi. Pri industrijskem postopku litja je potekalo sistematično vzorčevanje za različne preiskave: kemične analize, termodinamično računanje ravnotežnih faz s programi TCW in Computerm, dilatometrija v trdnem stanju, izračuni gostot izločenih mikrostrukturnih sestavin po programu TAPP 2.2, linearne meritve trdote, ugotavljanje mehanskih lastnosti pri sobni temperaturi in višjih temperaturah, svetlobna in elektronska mikroskopija, računanje procesa litja pri vseh treh fazah po metodi končnih elementov. Delovna plast valja je izdelana iz bele litine, legirane s kromom, medtem ko je jedro iz sive litine s kroglastim grafitom (SGI). Glavni poudarek je na srednji plasti, ki je narejena iz sive litine z luskastim grafitom. Mikrostrukturne sestavine so bile določene kvalitativno in kvantitativno. Gostote vsake od mikrostrukturnih sestavin so bile izračunane po zgoraj omenjenih programih. Ugotovljeno je bilo, da se gostote avstenita in karbidov tipa M_7C_3 med seboj razlikujejo za okoli 0,3 kg/dm^3, kar vpliva na porazdelitev mikrostrukturnih sestavin po prerezu valja zaradi centrifugalnih sil. Merjene in izračunane so bile tudi notranje napetosti v ulitku. Pojasnjeni so bili vplivi nehomogene porazdelitve karbidov v prvi in drugi plasti ter vpliv jedra iz SGI na mehanske lastnosti ulitka skupaj z notranjimi napetostmi.

Ključne besede: gradientni ulitki, bela litina, siva litina s kroglastim grafitom, računanje litja in napetosti, karakterizacija mikrostrukture

Abstract

This work deals with the problem of casting production of composed castings for rolls also called gradient castings. The technology of production is a combination of the horizontal centrifugal casting of alloyed white cast iron (two sequences) and gravity casting of cores which occurs in third sequence. From the industrial casting, the systematical sampling for different investigation methods was done. The following examination methods were used: chemical analyses, thermodynamic calculation of equilibrium phases by TCW and Computer programmes, dilatometry in the solid state, calculation of density for extracted microstructural components by programme TAPP 2.2, linear hardness measurements, determination of mechanical properties at room temperature and higher temperatures, optical and electron microscopy, FEM calculation of casting process for all three sequences of casting.Working layer of the roll is made from chromium alloyed white cast iron. The core is made by spheroidal graphite cast iron (SGI). The main focus was on intermediate layer, which is made from flake graphite cast iron. Microstructural constituents were determined quantitatively and qualitatively. With help of mentioned programmes, the calculation of density for each microstructural constituent was done. It was found out that austenite and M_7C_3 type of carbides have a difference in density for approximately 0,3 kg/dm^3 which influences the distribution of microstructural constituents in roll cross-section due to centrifugal forces. The internal stresses in the casting were also calculated and measured. The explanations of the influences of inhomogeneous carbide distribution in a first and the second layer and influence of core made of SGI on mechanical properties of the casting together with internal stress were also made.

Key words: gradient castings, white cast iron, spheroidal graphite cast iron, casting and stress calculations, characterization of microstructure

1 Uvod

Centrifugalno litje je postopek, pri katerem se kovina vliva in strjuje v vrteči se kokili zaradi centrifugalnih sil[1]. Smer strjevanja se pri centrifugalnem postopku razlikuje od smeri pri litju v pesek. Zaradi hitrega prehoda toplote na kokilo se začne kristalizacija na zunanji površini ulitka in napreduje v notranjost. Rezultat tega je drobnozrnata površinska plast, medtem ko strjevanje proti notranjosti poteka z rastjo dendritov[2].

Pri izdelavi valjev se uporablja kombinacija centrifugalnega in težnostnega litja, pri čemer se delovna in vmesna plast ulivata centrifugalno, jedro iz sive litine s kroglastim grafitom pa težnostno. Delovna plast je iz kromove bele litine, da se dosežeta trdota in obrabna trdnost, vmesna plast pa je iz neke vrste sive litine, da sta delovna plast in jedro dobro povezana, medtem ko je jedro iz sive litine s kroglastim grafitom, kar daje valju žilavost in togost[3].

Za plast kromove bele litine je želeno, da vsebuje čim manj zaostalega avstenita v osnovi in da mikrostruktura ne vsebuje perlita.

Osnova v ulitem stanju vsebuje občuten delež zaostalega avstenita (30-60 %), ki mora razpasti pri eno- ali večstopenjski toplotni obdelavi, da se doseže zahtevana mikrostruktura, ki vsebuje majhne in

1 Introduction

Centrifugal pouring technology is a casting process, where metal can be poured and solidified in a rotating permanent mould under the influence of centrifugal force. 1 The direction of solidification in centrifugal process differs from the sand casting. Due to the rapid transfer of heat to the permanent mould, crystallization starts on the outer surface of the casting and progresses towards the inside. The result is a fine-grained surface crust, further solidification towards the interior takes place with the growth of dendrite crystals. [2]

Combination of centrifugal and gravity casting is used at roll production, where working layer and intermediate layer are casted centrifugally and core is gravity casted from spheroidal graphite cast iron. Working layer is made of chromium white cast iron to achieve hardness and wear resistance, intermediate layer is sort of grey cast iron to produce good bonding of working layer and core while core is made of spheroidal graphite cast iron to obtain toughness of a roll. [3]

With chromium white cast iron layer, it is desirable to have as little as possible retained austenite in the matrix and that does not contain the pearlite phase in microstructure.

enakomerno porazdeljene karbide vrste M23C6 v kovinski osnovi α 4. Ker so ti zelo trdi in enakomerno porazdeljeni v osnovi, so za obrabno trdnost zelo pomembni sekundarni karbidi.

Ciljane mehanske lastnosti se dosežejo s toplotno obdelavo, pri kateri se ulitek segreje na temperaturo avstenitizacije in krmiljeno ohlaja do sobne temperature. Takšna obdelava omogoča dober nadzor nad izločanjem sekundarnih karbidov v temperaturnem območju 800-1050 ^{o}C.

2 Eksperimentalni del

Vzorci, vzeti iz delovne in vmesne plasti ter jedra, so bili analizirani in preiskani s svetlobno in elektronsko mikroskopijo (SEM) z EDS, merjene so bile natezne trdnosti pri različnih temperaturah, trdote in dilatometrski raztezki. Gostote strjenih faz so bile izračunane s programom TAPP 2.2 in termodinamična fazna ravnotežja s programsko opremo Thermo-Calc.

Kemične sestave vseh treh plasti so v razpredelnici 1.

3 Rezultati in razprava

Slika 1 prikazuje mejno plast delovne plasti, vmesno plast in jedro valja. Mikrostruktura

In as-cast state, the matrix contains a substantial proportion of residual austenite (30–60 %), which is necessary to decompose with single or multistage heat treatment, in order to achieve the required microstructure, which contains small and evenly distributed $M_{23}C_6$ type carbides in α-metallic matrix.[4] Due to their high hardness and uniform distribution in the matrix, secondary carbides are of great importance for wear resistance.

Target mechanical properties are obtained by heat treatment, where casting is heated to austenitising temperature and control cooled to room temperature. Such treatment allows a good control over the segregation of secondary carbides in the temperature range from 800 to 1050 °C.

2. Experimental

Analyses were carried out on samples taken from working layer, intermediate layer and core. Optical microscopy, scanning electron microscopy (SEM) with EDS-analysis, tensile tests at various temperatures, hardness measurements and dilatometric analysis were carried out. Densities of solidified phases were calculated by TAPP 2.2 programme and thermodynamic phase equilibrium calculations performed by Thermo-Calc software.

Razpredelnica 1: Kemična analiza gradientnega ulitka (mas. %)

Table 1: Chemical analysis of gradient casting (mass fraction, %).

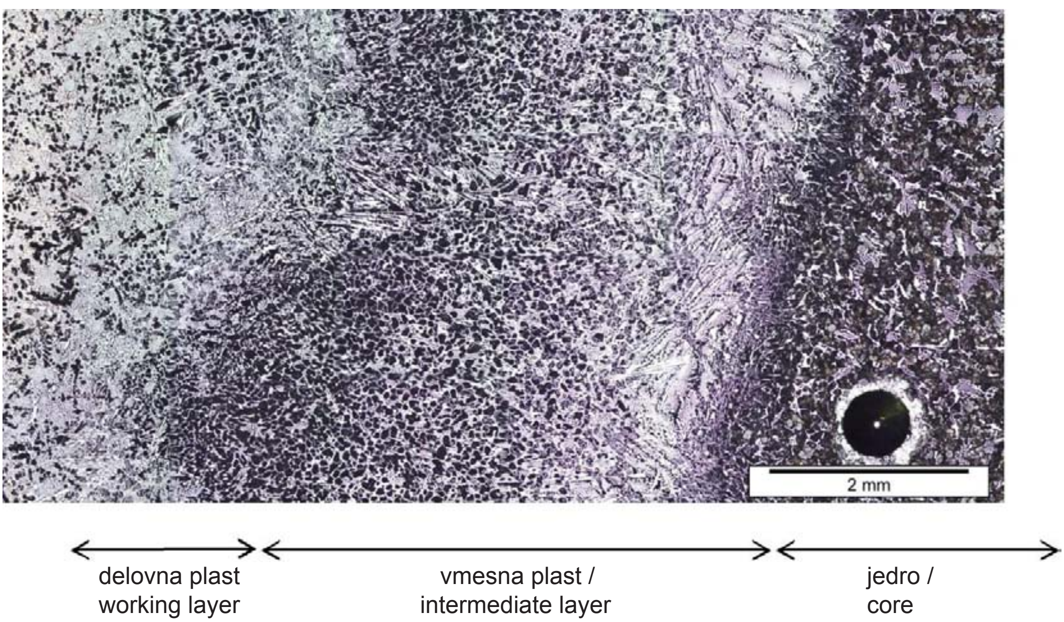
	C	Si	Mn	P	S	Cr	Ni	Mo	Mg	Cu	Sn	Al	V	Ti	W	Co	Fe
Delovna plast / Working layer	2,799	0,703	0,965	0,030	0,037	16,681	1,433	1,154	0,003	0,081	0,000	0,0000	0,296	0,000	0,000	0,000	75,818
Vmesna plast / Intermediate layer	3,118	1,034	0,342	0,026	0,010	0,129	0,247	0,029	0,000	0,039	0,005	0,0013	0,012	0,006	0,009	0,018	94,965
Jedro / Core	3,002	2,734	0,366	0,031	0,007	0,131	0,247	0,029	0,099	0,039	0,007	0,0229	0,013	0,007	0,009	0,017	93,198

delovne plasti je sestavljena iz avstenita in karbidov, ker je zlitina bogata s kromom. Vmesna plast, ki se zliva z jedrom, je zelo bogata s karbidi M_7C_3. Pri strjevanju vmesna plasti nastanejo v talini najprej primarni kristali avstenita, ki se zaradi centrifugalne sile in večje gostote od ostale taline začno pomikati proti delovni plasti. Talina vmesne plasti ponovno stali tanko plast delovne plasti in nekateri karbidotvorni elementi, posebno krom, se raztopijo v vmesni plasti, kar povzroči tvorbo karbidov in zaradi manjše gostote od γ-Fe se izločijo v plasti med vmesno plastjo in jedrom. Velika količina karbidov se dobro vidi na sliki 1. Dovolj velik interval strjevanja in manjša hitrost ohlajanja povzročita, da nastane plastovita vmesna plast, ki pa ni želena mikrostruktura. Karbidi, ki niso enakomerno razpršeni v kovinski osnovi, predstavljajo krhko plast v ulitku.

Chemical compositions of all three layers are presented in table 1.

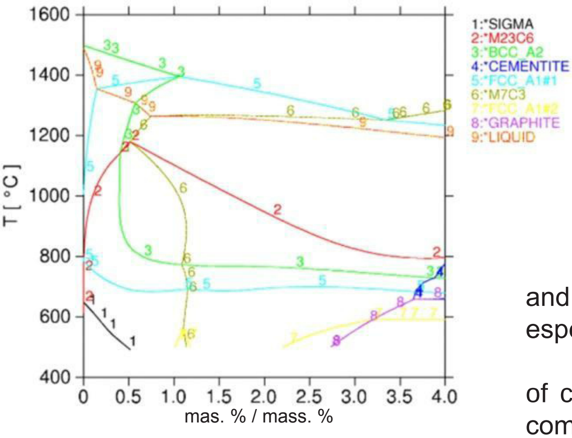
3 Results and Discussion

Figure 1 presentsthe boundary layer of working layer, intermediate layer and core of a roll. Microstructure of working layer consists of austenite and of carbides since alloy is rich on chromium. The intermediate layer, which merges with the core, is highly rich of M_7C_3 carbides. At solidification of the intermediate layer melt in the first stage the formation of primary austenite crystals occurs, which by means of centrifugal force due to higher density than the rest of the melt start to impose towards the direction of the working layer. Melt of intermediate layer remelts a thin layer of a working layer



Slika 1: Makrostruktura delovne in vmesne plasti ter jedra

Figure 1: Macrostructure of a working layer, intermediate layer and a core



Slika 2: Izopletni fazni diagram delovne plasti

Figure 2: The isopleth phase diagram of working layer

Slika 2 prikazuje izopletni fazni diagram za material delovne plasti. Strjevanje začenja s strjevanjem avstenita, ki mu sledi evtektična reakcija ob strjevanju karbidov vrste M_7C_3 med 1260 °C in 1230 °C. Strjevanje karbidov vrste $M_{23}C_6$ poteka pri 820 °C.

Gostote evtektičnih karbidov M_7C_3 in avstenita so bile izračunane pri ustreznih temperaturah s programom TAPP 2.2. Gostota karbida M_7C_3 je bila pri temperaturi izločanja 6,738 kg/dm^3, medtem ko je bila gostota avstenita pri temperaturi njegovega izločanja 6,99 kg/dm^3. Zdi se, da ta relativna razlika med gostotami avstenita in karbidov v talini povzroča pri strjevanju vmesne plasti nastanek slojev obeh mikrostrukturnih sestavin. V prvi fazi strjevanja se pojavijo dendriti avstenita, ki jih centrifugalne sile potisnejo zaradi njihove večje gostote proti delovni plasti. Ko se temperatura preostale taline zniža do temperature evtektičnega strjevanja, kar povzroči nastanek kali in rast karbidov, potisnejo centrifugalne sile karbide, ki so lažji od avstenita, proti območju med vmesno plastjo in jedrom. Čeprav je razlika gostot avstenita in karbidov le 0,3 kg/dm^3, postane ta razlika pomembna pri centrifugalnih silah 120 G, kar pripelje do nastanka nehomogene mikrostrukture.

and some carbide promoting elements, especially chromium, dissolves in

intermediate melt causing the formation of carbides, and due to the lower density compared with the γ begin to deposit on the interface of intermediate layer and core. Large amount of carbides is well seen on figure 1. Sufficient solidification interval and a lower cooling rate are necessary to produce so stratified intermediate layer, which is undesirable microstructure. Carbides, which are not evenly dispersed on the metal matrix, represent a brittle layer in the casting.

Figure 2 is showing the isopleth phase diagram of working layer material. Solidification starts with solidification of austenite followed by eutectic reaction with solidification of M_7C_3 type carbides between 1260 and 1230 °C. Precipitation of $M_{23}C_6$ type carbides is taking place at 820 °C.

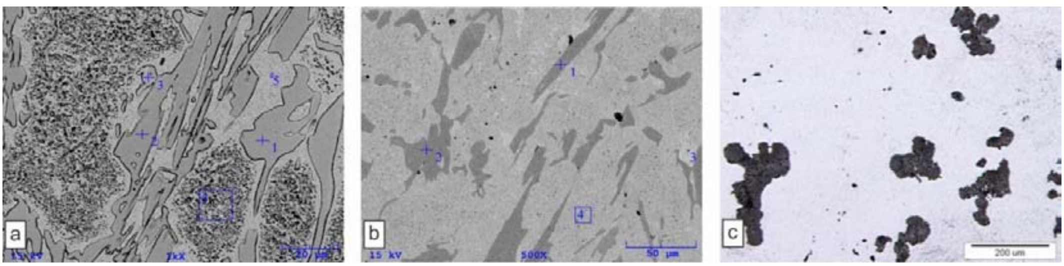
With the help of the programme TAPP 2.2, the density of eutectic M_7C_3 carbides and austenite at reference solidification temperature were calculated. Density of carbide M_7C_3 is 6.738 kg/dm^3 at temperature of precipitation; austenite has a density of a 6.99 kg/dm^3 at a temperature of precipitation. Given the relative difference in density between the austenite, carbides and the melt in the solidification stage of intermediate layer, it seems that stratification of both microstructural ingredients occurs. In first stage austenite dendrites appear and are pushed by centrifugal forces and higher density in direction near the working layer. When the temperature of

Slika 3a prikazuje SEM-mikroposnetek delovne plasti, v kateri so veliki delci karbidi, nastali pri evtektičnem strjevanju. EDS analiza kaže, da so ti delci karbidi vrste M_7C_3. Manjši delci v osnovi so karbidi vrste $M_{23}C_7$, ki se izločajo v trdnem stanju iz trdne raztopine avstenita. Jasno je, da se je med toplotno obdelavo praktično ves avstenit pretvoril v martenzit. Vmesna plast tudi vsebuje karbide. Z EDS-analizo je bilo ugotovljeno, da so to karbidi vrste M_7C_3, kar se vidi na sliki 3b. Obstaja še majhna količina manjših delcev, ki so porazdeljeni v osnovi martenzita, toda ta količina je mnogo manjša, ker je tu tudi količina karbidotvornih elementov občutno manjša kot v delovni plasti. Slika 3c kaže mikroposnetek poliranega vzorca jedra v svetlobnem mikroskopu, kjer se vidi grafit v železovi osnovi. Grafit naj bi bil kot kroglice, vendar ni, verjetno zaradi neustrezne obdelave taline z Mg in odgora magnezija med dolgotrajnim strjevanjem jedra.

Slika 4 prikazuje EDS-spekter analiziranih mikrostrukturnih sestavin, označenih na slikah 3a in 3b.

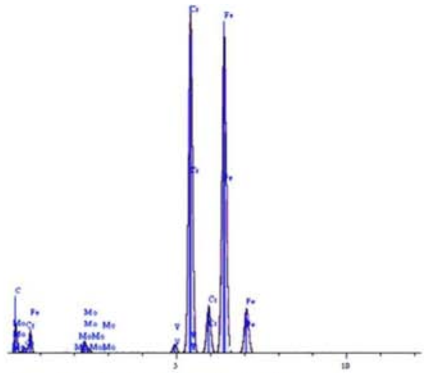
Izmerjene so bile trdote po Rockwellu od površne valja do globine 80 mm. Slika 5 prikazuje trdoto delovne plasti, ki je bila okoli 61 HRC do globine 600 mm, kjer se začenja vmesna plast. V tej plasti se je the remaining melt falls within the scope of eutectic solidification, leading to the development of nucleation and growth of the carbides they are pushed in the direction of interface between intermediate layer and core since carbides have lower density than austenite. The difference in density between the austenite and carbide is only 0,3 kg/dm^3 but the difference is much significant at centrifugal forces of 120 G leading to inhomogeneous microstructure development.

Figure 3a shows a SEM-microphotograph of working layer where large particles are carbides solidified during eutectic reactions. EDS-analysis show that these should be carbides of M_7C_3 type. Smaller particles in the matrix are carbides of $M_{23}C_6$ type precipitated in solid state from the solid solution of austenite. It is clear that practically whole austenite was transformed into martensite during heat treatment. Intermediate layer also contains carbides, determined by EDS-analysis to be M_7C_3 type seen on figure 3b. There is some small amount of smaller particles of secondary carbides distributed in the martensite matrix but the amount is much lower since the concentration of carbide promoting elements is much lower than in working layer. Figure 3c shows optic



Slika 3: Mikrostrukture vseh treh plasti: SEM-mikroposnetek delovne plasti (a), SEM-mikroposnetek vmesne plasti (b) in mikroposnetek jedra v svetlobnem mikroskopu (c)

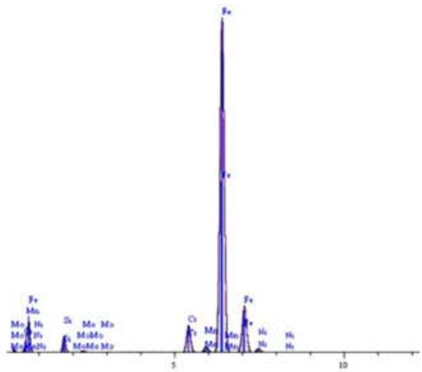
Figure 3: Microstructures of all three layers: SEM microphotograph of working layer (a), SEM microphotograph of intermediate layer (b) and optic microphotograph of core(c)



Elt.	Line	Intensity (c/s)	Error 2-sig	Atomic %	Conc		
C	Ka	11.95	0.893	14.643	3.640	wt.%	
V	Ka	5.75	0.619	0.721	0.760	wt.%	
Cr	Ka	227.47	3.894	32.331	34.790	wt.%	
Fe	Ka	229.32	3.910	51.870	59.948	wt.%	
Mo	La	6.08	0.637	0.435	0.863	wt.%	
				100.000	100.000	wt.%	Total

kV 15.0
Takeoff Angle 35.0°
Elapsed Livetime 60.0

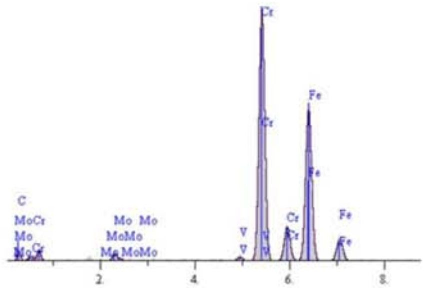
a



Elt.	Line	Intensity (c/s)	Error 2-sig	Atomic %	Conc		
C	Ka	2.22	0.384	2.928	0.651	wt.%	
Si	Ka	14.12	0.970	1.905	0.991	wt.%	
Cr	Ka	31.77	1.455	3.118	3.002	wt.%	
Mn	Ka	2.32	0.394	0.377	0.384	wt.%	
Fe	Ka	429.21	5.349	89.995	93.056	wt.%	
Ni	Ka	4.58	0.553	1.538	1.671	wt.%	
Mo	La	1.91	0.357	0.138	0.245	wt.%	
				100.000	100.000	wt.%	Total

kV 15.0
Takeoff Angle 35.0°
Elapsed Livetime 60.0

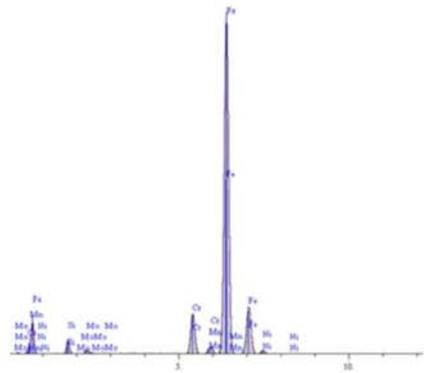
b



Elt.	Line	Intensity (c/s)	Error 2-sig	Atomic %	Conc		
C	Ka	6.76	0.923	8.703	2.071	wt.%	
V	Ka	4.39	0.744	0.592	0.598	wt.%	
Cr	Ka	286.31	6.005	44.753	46.103	wt.%	
Fe	Ka	186.63	4.849	45.465	50.304	wt.%	
Mo	La	6.55	0.908	0.487	0.925	wt.%	
				100.000	100.000	wt.%	Total

kV 15.0
Takeoff Angle 35.0°
Elapsed Livetime 31.8

c



Elt.	Line	Intensity (c/s)	Error 2-sig	Atomic %	Conc		
C	Ka	0.76	0.225	1.039	0.227	wt.%	
Si	Ka	10.85	0.851	1.521	0.778	wt.%	
Cr	Ka	46.22	1.755	4.983	4.718	wt.%	
Mn	Ka	2.50	0.408	0.428	0.428	wt.%	
Fe	Ka	414.41	5.256	90.442	91.980	wt.%	
Ni	Ka	3.82	0.505	1.333	1.425	wt.%	
Mo	La	3.37	0.474	0.254	0.444	wt.%	
				100.000	100.000	wt.%	Total

kV 15.0
Takeoff Angle 35.0°
Elapsed Livetime 60.0

d

Slika 4: EDS-spektri faz: karbidi M7C3, mesto 1 na sliki 3b (a), martenzit, mesto 3 na sliki 3b (b), karbidi M23C6, mesto 6 na sliki 3a (c) in martenzit s karbidi M23C6, mesto 4 na sliki 3b

Figure 4: EDS-spectrums of phases: M_7C_3 carbide, spot 1 on figure 3b (a), martensite, spot 3 on figure 3b (b), carbides $M_{23}C_6$, spot 6 on figure 3a (c) and martensite with carbide $M_{23}C_6$, spot 4 on figure 3b

trdota zmanjševala do jedra, kjer je bila trdota samo 32 HRC.

Natezni preizkusi vzorcev delovne plasti pri različnih temperaturah so pokazali, da se je natezna trdnost do temperature 400 ºC zmanjšala za okoli 10 %, pri višjih temperaturah pa se je zmanjševala še hitreje in dosegla vrednost le 200 MPa pri 700 ºC. To pomeni, da je delovna plast nagnjena k pokanju med ohlajanjem po litju, ker ima jedro mnogo višjo temperaturo, kar povzroča natezne napetosti v delovni plasti.

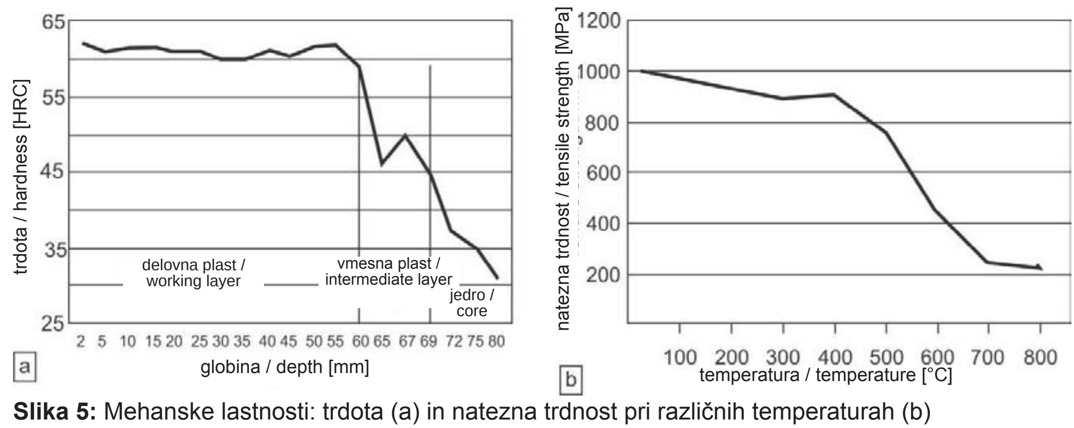
Slika 6 prikazuje rezultate dilatometrske analize za dva vzorca delovne plasti, en vzorec vmesne plasti in en vzorec jedra. Delovna plast je pokazala najmanjše raztezanje od sobne temperature do 1100 ºC. Vmesna plast je imela rahlo večje raztezanje pri najvišjih temperaturah, jedro pa največje raztezanje. Te razlike raztezanja povzročajo velike notranje napetosti med ohlajanjem gradientnega ulitka. Jasno je, da se pri ohlajanju ulitka površina (delovna plast) krči hitreje kot jedro, kar povzroča natezne napetosti v delovni plasti in to lahko vodi do pokanja. Podobne razmere so pri toplotni obdelavi valja, kjer se ves ulitek segreje na temperaturo avstenitizacije.

microphotograph of a core in a polished state where graphite in iron matrix is seen. Graphite should be in nodule like form but it is not probably due to insufficient Mg-treatment and burn-off of Mg during long solidification time of a core.

Figure 4 presents EDS spectrums of analyzed microstructural constituents marked on figures 3a and b.

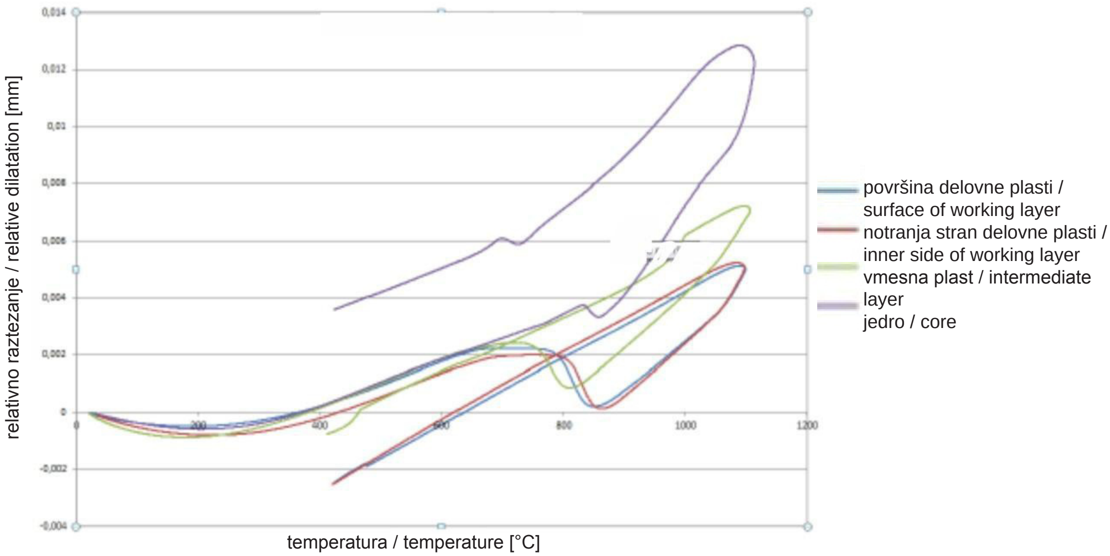
Rockwell Hardness measurements from surface of the roll to the 80 mm depth were carried out. Figure 5 presents hardness of a working layer which is around 61 HRC till the 600 mm in the depth when intermediate layer starts. In this layer hardness starts to descend and proceeds to descend into the core too where the hardness is only 32 HRC.

Tensile tests of working layer at different temperatures are presenting that tensile strength is lowered for about 10 % at 400 °C and at higher temperatures is lowered even faster and reaches only 200 MPa at 700 °C. This means that working layer has a tendency of crack formation during cooling after casting since core has much higher temperature and is causing tensile stresses in the working layer.



Slika 5: Mehanske lastnosti: trdota (a) in natezna trdnost pri različnih temperaturah (b)

Figure 5: Mechanical properties: hardness (a) and tensile strength at different temperatures (b).



Slika 6: Dilatacijske krivulje vzorcev različnih plasti

Figure 6: Dilatation curves of samples at different layers.

Jedro se razteza bolj kot delovna plast, kar znova povzroča natezne napetosti. Na sliki 6 se vidi, da je bila kvantitativna razlika pri raztezanju vzorcev 0,055 mm pri 1000 oC, kar ni zanemarljiva vrednost.

Napetosti, ki jih povzroča različno raztezanje posameznih plasti pri strjevanju in ohlajanju ulitka so bile tudi izračunane s programsko opremo Procast. Vidi se, da so bile največje natezne napetosti dosežene ravno na meji med vmesno plastjo in jedrom, kar vodi do pokanja, potem pa je valj neuporaben zaradi luščenja [5].

4 Sklepi

Ugotovljeno je bilo, kako poteka strjevanje različnih plasti. Očitno je, da vmesna plast natali delovno plast in se nekaj karbidotvornih elementov raztopi v talini vmesne plasti, kar povzroči nastanek karbidov vrste M_7C_3. V delovni plasti so tudi sekundarni karbidi vrste $M_{23}C_6$.

Figure 6 presents dilatometric analysis of for samples, two from working layer, one from intermediate layer and one from core. It is seen that working layer has the lowest dilatation in the temperature range from room temperature up to 1100 °C. Intermediate layer has slightly higher dilatation at the highest temperature but the core has the highest dilatation. These differences in dilatation are causing high internal stresses during cooling of the gradient casting. It is clear that when the casting is cooling the surface – the working layer in this case is shrinking faster than the core, which causes tensile stresses in the working layer, which might lead to a crack formation. Similar situation is met at heat treatment of the role, where whole casting is heated to austenitising temperature and core expands more than working layer causing tensile stresses again. From figure 6 it is seen that quantitative difference in

Karbidi M_7C_3 imajo manjšo gostoto od avstenita, kar je vzrok, da so ti pri počasnem strjevanju vmesne plasti zaradi velikih centrifugalnih sil potisnjeni v notranji del plasti. Tako nastane nehomogena mikrostruktura.

Natezna trdnost delovne plasti se ne spreminja do 500 °C, potem pa se hitro zmanjšuje, kar vodi do odpovedi valja, če delovne temperature dosežejo take vrednosti.

Trdota po prerezu valja se v vmesni plasti zmanjšuje, kar je posledica manjše koncentracije primarnih in sekundarnih karbidov.

Dilatometrska analiza je pokazala velike razlike pri koeficientih linearnega raztezanja različnih plasti. Razlika pri raztezanju delovne plasti in jedra je 0,055 mm pri 1000 °C. Takšne razlike lahko povzročijo težave že med ohlajanjem ulitka po strjevanju ali pa med nadaljnjo toplotno obdelavo.

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dilatation of samples is 0,055 mm at 1000 °C which is not insignificant value.

Stresses caused by different dilatations of layers at solidification and cooling of the casting were also calculated by Procast software. It is seen that the highest tensile stresses are reached just at the interface between intermediate layer and the core, which can lead to a crack formation and a failure of a role such as spall. [5]

4 Conclusions

Solidification of different layers was determined. It is clear that intermediate layer remelts the working layer and some carbide promoting elements dissolve in an intermediate layer melt, which cause formation of M_7C_3 type carbides. Working layer consists of secondary carbides too of a $M_{23}C_6$ type.

M_7C_3 type carbides have lower density then austenite which are a reason that at slow solidification of intermediate layer the formed carbides are pushed by high centrifugal forces into inner side of the layer. Inhomogeneous microstructure is obtained in this way.

Tensile strength of a working layer is not changed until 500 °C, then is rapidly lowered which can lead to role failure if such working temperatures are reached.

Hardness of the role cross-section is lowering in intermediate layer and in role as a result of lower concentration of primary and secondary carbides.

Dilatometric analysis showed high differences in linear expansion coefficients of different layers. The difference in the dilatation of a working layer and a core is 0,055 mm at 1000 °C. Such differences may cause problems already during cooling of the casting after solidification or during the following heat treatment.